Terrestrial Laser Scanning (Ground-Based Lidar) Methods and Applications in Geologic Research and Education

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w/ slides from D. Phillips, UNAVCO & J. Oldow, UTD
Location of Study Area (San Gabriel, California)
Los Angeles County 30m DEM

J. Oldow, UTD
San Gabriel Mountain 1m DEM from airborne lidar

J. Oldow, UTD
El Mayor-Cucapah Earthquake

- April 4, 2010
- Mw 7.2
- ~100km rupture
- CA-Mexico border to the gulf

- > 3m right-normal slip north of epicenter
- < 1m right-normal blind faulting south of epicenter

P. Gold, UCD
Motivations: Data Collection

• Preserve primary rupture features for:
  • Remote measurement/analysis
  • Comparison to future scans

• Scan ruptures in a variety of geologic and geomorphic settings
Scale of TLS coverage

-~200m along-strike distances

Shaded T-lidar point cloud

View to SW

Photo from helicopter

Borrego Fault

Scarp Height = 1.6m

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Data Collection

TLS boundary
2010 rupture

Reg. target
Scan position

Vegetation

schematic x-sxn

Site 3
(Riegl scanner)

• 3 days
• 19 scan pos.; 9 target pos.
• ~100 million pts
• 0.15 km^2, 500 pts/m^2

Vegetation schematic x-sxn

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Data Collection
Data Collection

Site 4 (Trimble scanner)

• 1 day
• 4 scan positions; 5 target positions.
• ~13 million points
• 0.03 km², 450 pts/m² schematic x-sxn

P. Gold, UCD
• Spot size (range, divergence)
• Spot spacing (range, angular resolution)
• Spot density (range, angle, number of setups)
• Angle of incidence (spot shape, intensity, range)
• Edge effects
• First return, last return, “other”
• Shadows
• Scan object characteristics (albedo, color, texture)
• Field of View
• Points Per Second
Beam Divergence

\[ D_f = (\text{Divergence} \times d) + D_i \]
Beam Divergence
Angular Step

Spacing = \( d(m) \times \text{TAN}(\text{step}) \)
Angular Step
Riegl VZ400 Maximum measurement range as function of target material
Scan Positions

Choose scan positions to minimize occluded (shadowed or hidden) geometries.
Shot Spacing / Sample Density

- Shot spacing varies as a function of range to target.
- Choose angular scan resolution to optimize sample density.
Standard tie point workflow (e.g., Riegl RiScan Pro)

- Use at least 5 reference targets to register scan positions (the more the better).
- Same targets must be common between scan positions.
- The more targets common to all scan positions, the better

In the field

- Determine scan locations, target locations and GPS locations.
- Set up targets and GPS.
- Scan position 1
  - 360-deg “panorama” scan + Image acquisition if desired.
  - Target fine scan.
  - Area of interest scan + Image acquisition if desired.
- Scan positions 2 +
  - Same as above but then find corresponding points and co-register scan positions.
Moab, Utah survey site
TLS Instrument and Survey Parameters

Multiple survey positions

Moab Utah
Survey Tie Points
A note on coordinate systems:

- Three types of coordinate systems used in TLS:
  - Scanner coordinates (Riegl = “SCS”)
  - Project coordinates (“PRCS”)
  - Global Coordinates (GLCS)

- Remember the scanner thinks only in **angles and distances**

- Initially, all scans are independent w/ measurements relative to position of the scanner.

- Tie points link scans together = project coordinates (PRCS)

- Independent GPS information allows georeferencing of data (GLCS)
Data volume can be a problem:

- Technology outpaces most software for data processing & management.

  - *Just because you can, doesn’t mean you should*

- Science application should define data collection.
TLS Workflow Overview

1. Project Planning (Targets, Priorities, Field Constraints, Logistics, Costs, etc.)
2. Data Collection (TLS, GPS, Photos, etc.)
3. Registration (and Geo-Referencing) of Scans from Single Campaign
4. Editing and Cleaning of Point Cloud Data

Point cloud data reformatting (e.g. manufacturer proprietary format to ASCII, LAS, etc.) and/or interpolation.

- Integration with Other Datasets (e.g. airborne LiDAR, GPR, GIS)
- Photorealistic Modeling
- Surface Modeling
- Combination of Scan Data from Multiple Campaigns (e.g. Time Series)
- More Editing and Cleaning of Point Cloud Data
Point Cloud

- 3D “point cloud” of discrete locations derived from range and orientation of scanner for each laser pulse.

- XYZ position in cartesian coordinates plus associated point attributes: intensity, RGB, etc.

- 3D point clouds are the basis for subsequent analysis and used to create CAD or GIS models

- Typically ASCII XYZ + attributes or LAS
  - E57 = New standard under development, minimal adoption

- UNAVCO *standard deliverable* = merged, aligned, georeferenced point cloud in ASCII or LAS format.
TLS Data

Intensity

Range

Height

True Color
TLS data often delivered in Earth Centered, Earth Fixed coordinates.

- Origin = center of mass of the Earth.
- Three right-handed orthogonal axis X, Y, Z. Units = meters.
- The Z axis coincides with the Earth’s rotation axis.
- The (X,Y) plane coincides with the equatorial plane.
- The (X,Z) plane contains the Earth’s rotation axis and the prime meridian.

- Preferred by geodesy community
- Not GIS friendly! Requires transformations into 2D cartesian (e.g., UTM).
- Application of data matters
- Beware vertical datums...
9. What software do you use to process and/or analyze TLS data? Choose all that apply.

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Other (please specify) 32
TLS Processing Workflow – Software

Other:
• 3D Studio
• 3dReshaper
• AutoCad
• BCAL LiDAR Tools
• Blender
• CloudWorx
• Crusta
• ENVI
• FARO Scene
• GDAL
• GeoAnalysis Tools
• Geovisionary
• Global Mapper
• GMT
• GRASS
• IDL
• Kingdom Suite
• LASTools
• libLAS
• MapScenes
• MapTek I-SiTE Studio
• Meshlab
• MicroCad
• MicroStation
• MicroSurveyCAD
• OpenTopography DEM generator
• OpenVC
• Point Cloud Library (PCL)
• Points2Grid
• PointTools
• Python modules and
• custom tools
• RealityLinx
• Split-FX
• Surfer
• TerraModeler
• Trimble RealWorks
• UC Davis tools
• (LidarViewer, Crusta)
• “home grown software”
TLS Processing Workflow – Overview

Field data collection + data post-processing

Merged, aligned, georeferenced point cloud

Data cleaning & thinning

Vegetation filtering & classification

Surface generation (DEMs etc)

Raster data products & surfaces (DEMs)

Analysis & science!
Vegetation is a headache is geoscientists

- *Our noise is someone else’s signal*
- How to get good ground model?
- Automated vs manual?
Commercial – Automated:

- RiScan Pro, TeraSolid, etc.

Open Source - Automated:

- LASTools –
  lasground.exe &
  lasclassify.exe
- MCC-lidar
  (Evans & Hudak, 2007)
  http://sourceforge.net/apps/trac/mcclidar/
- BCAL lidar tools (requires ENVI): http://bcal.geology.isu.edu/tools-2/envi-tools

More discussion: http://www.opentopography.org/index.php/blog/detail/tools_for_lidar_point_cloud_filtering_classification#comments

Open Source - Manual:

- LidarViewer (KeckCAVES)
• Digital representation of topography / terrain
  – “Raster” format – a grid of squares or “pixels”
  – Continuous surface where Z (elevation) is estimated on a regular X,Y grid
  – “2.5D”

• Grid resolution is defined by the size in the horizontal dimension of the pixel
  – 1 meter DEM has pixels 1 m x 1m assigned a single elevation value.

Source: http://www.ncgia.ucsb.edu/giscc/extra/e001/e001.html
• LiDAR from EarthScope data

• Example from flat area with little or no vegetation so ground is sampled approx. 5+ times per square meter

• How do we best fit a continuous surface to these points?

• Ultimately wish to represent irregularly sampled data on a regularized grid.
Triangulated Irregular Network (TIN)

Inverse Distance Weighted (IDW)

Kriging

Regularized Spline with Tension and smoothing (RST)

Figure from Helena Mitasova (NCSU): http://skagit.meas.ncsu.edu/~helena/gmslab/index.html
Massive volume of point cloud data that need to be gridded presents unique challenge to many traditional GIS interpolation approaches.

- Computation time becomes a serious concern

Global vs Local fit

- Global fit uses elevations from the region to estimate unknown elevation at the grid node.
  - Ex: Kriging, Trend Surface Analysis, splines
  - Computationally intensive and require segmentation approaches to break input data into pieces which can be processed independently.

Often inexact interpolators

- Surface does not exactly fit all points.
- Works well in areas where ground is poorly sampled.
• Triangular Irregular Networks (TIN)
  – Constructed by triangulating a set of points
  – Linear interpolation where points are fit exactly
  – Computationally efficient
  – Preserve heterogeneity of detail in sampling
  – Vector-based format so conversion to grid is necessary for many types of analysis.
• Global vs Local fit cont.:
  – Local fit only uses elevations immediately surrounding the grid node to estimate elevation.
    • Nearest neighbor, local binning, moving window
    • For all points that fall within the defined search area, apply mathematical function e.g. $Z_{\text{mean}}$, $Z_{\text{min}}$, $Z_{\text{max}}$, $Z_{\text{idw}}$

• Computationally efficient

• Not interpolation!

• Works well when: **Sampling density > grid resolution**

Ex: sampling density = 5 shots/m²  
grid resolution = 1 m
Community-wide need to standardize and document TLS data processing workflow & products:

- Metadata content and format
- Generic (vendor neutral/open) exchange formats (e.g., LAS, E57)
- Capture of intermediate data products (e.g., point cloud per scan position)
- Attributes associated with final L2 data product (merged, aligned, georeferenced point cloud)
- Provenance – capture all steps of workflow to ensure repeatable and verifiable science.

Currently industry-wide deficiencies in this area – UNAVCO trying to take a leadership role.
Terrestrial Laser Scanning Project Summary

**Project Planning**
- Choose instrument based on capabilities and science/data goals.
- Schedule based on instrument availability, science requirements, environmental factors.
- Use Google Earth, field site photos, etc. to establish preliminary locations for scan positions, control targets, registration targets, etc.

**Instrument calibration & data collection**

**Post-processing & Analysis**
- Make a copy of the data collected in the field. Keep the original project(s) in a safe place. Post process using the copy of the project.

**Metadata**
- Project summary document.
- GPS data (raw files, rinex files, antenna heights, log sheets, etc.).
- Field photos.
- Google Earth files, etc.